

Sex Differences in the Sciatic Notch of Great Apes and Modern Humans

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ABSTRACT The sciatic notch has been widely used as a sexing criterion in modern humans. In order to better understand the sex differences of this feature in modern humans and great apes, four measurements of the sciatic notch were taken on samples of modern humans and great apes of known sex. Univariate (ANOVA) analysis and discriminant function analysis were performed on the extant taxa to determine: (1) the discriminating power of each variable in these samples of known group membership; and (2) which of these extant taxa shows the best discrimination between the sexes for the sciatic notch. Of the four extant taxa, the sciatic notch of *Homo sapiens* is the most sexually dimorphic, followed by *Gorilla gorilla*, and more weakly by *Pongo pygmaeus*, while *Pan troglodytes* is the least dimorphic of these taxa. Since the presence of a well defined sciatic notch is a hominid trait resulting from the dorsal extension of the posterior ilium, the close approximation of the sacrum to the acetabulum, the shortened ischium, and the accentuation of the ischial spine as part of the bipedal adaptation, it seems likely that the configuration of the sciatic notch in hominids was initially related to bipedalism, not reproduction. The development of sex differences in the sciatic notch of modern humans is more likely to have occurred after the transition to bipedality. © 1996 Wiley-Liss, Inc.

The greater sciatic notch has been recognized as an important, yet potentially variable, sex determinant in modern humans (Derry, 1923; Straus, 1927; Ince and Young, 1940; Mednick, 1955; Thieme and Schull, 1957; Washburn, 1948, 1949; Hanna and Washburn, 1953; Chopra, 1962; Krogman, 1962; Phenice, 1969; Bass, 1971; Kelley 1979; Segebarth-Orban, 1980; McLaughlin and Bruce, 1985, 1986; Hager, 1989). Human female notches have been characterized as shallow and broad whereas in modern human males the sciatic notch is typically narrow and deep.

Measurement of the sciatic notch has traditionally been based on the breadth, depth, and/or angle of the notch (e.g., Straus, 1927; Mednick, 1955; Thieme and Schull, 1957; Washburn, 1948, 1949; Hanna and Wash-

burn, 1953; Krogman, 1962; Bass, 1971). While the general sexual differentiation of the notch can be judged from these techniques, they may not offer the best means of delineating the manner in which the notch actually differs in males and females.

Following the earlier work of Lazorthes and Lhez (1939) and Letterman (1941), Genovés (1954, 1959) demonstrated the significance of measuring the relative proportions of the anterior and posterior chords of the sciatic notch rather than solely the maximum depth, breadth, or angle. He found that

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in modern human males the anterior chord exceeds the posterior one, while in modern human females the anterior and posterior chords are of equal proportions or, in some instances, the posterior chord actually exceeds the anterior one. Jovanović and Živanović (1965), modifying the points of measurement, reached similar conclusions regarding the relative proportions of the chords in modern human males and females from Central Europe. Davivongs (1963) also applied this technique to Australian aborigine pelves but the sample was of unknown sex. Dibennardo and Taylor (1983) and Taylor and Dibennardo (1984) examined two of these sciatic notch measurements in their analysis on modern humans: the maximum breadth of the notch (notch height in their terminology) and the anterior chord (notch position). They found that these traits show excellent reliability in sex determination and confirm Genovés' (1959) observations on the relative proportions of these chords in modern males and females.

Employing Genovés' technique of measuring the relative proportions of the sciatic notch chords, this paper compares the sciatic notch of modern humans of known sex to the sciatic notch of great apes of known sex. The sciatic notch of the great apes has not been examined for sex differences because it is generally thought they lack well defined notches due to their relatively long ilia. While not as well demarcated as in modern humans, great ape sciatic notches are present and can be measured using similar points of measurement as in humans. The purpose of this analysis is to elucidate the nature of sex differences in the sciatic notch of great apes and compare these to the differences observed in modern humans.

MATERIALS AND METHODS

Materials

Measurements of the sciatic notch were taken on: (1) modern humans of known sex; and (2) modern great apes of known sex. Written records indicate that sex was determined on all specimens from examination of the soft tissues. The modern human skeletal material used is from four collections (Table 1): the Raymond Dart Collection housed at the Department of Anatomy, University of

TABLE 1. Comparative samples of extant taxa

Taxon collection	
<i>Homo sapiens</i> (n = 100)	
males = 49	Raymond Dart, Hamann-Todd,
females = 51	Weisbach, Terry, British Museum (Natural History)
<i>Gorilla gorilla</i> (n = 46)	
males = 23	Powell-Cotton, Hamann-Todd,
females = 23	Smithsonian Institution ^a
<i>Pan troglodytes</i> (n = 58)	
males = 28	Powell-Cotton, Hamann-Todd,
females = 30	Smithsonian Institution
<i>Pongo pygmaeus</i> (n = 23)	
males = 9	Smithsonian Institution
females = 14	

^a Includes two males and two females of *G.g. beringei*.

Witwatersrand, Johannesburg, South Africa; the Hamann-Todd Collection, Cleveland Museum of Natural History, Cleveland, OH; the Terry Collection, Smithsonian Institution in Washington, DC; and the Weisbach Series housed at the Natural History Museum of Vienna, Austria. From the British Museum (Natural History), one male and one female pygmy (Bambuti and Akka tribes, respectively) were also examined.

The great ape material used in this study is from the three collections (Table 1): the Powell-Cotton collection housed at the Powell-Cotton Museum in Birchington, Kent, England; the Hamann-Todd Collection from the Cleveland Museum of Natural History; and the Smithsonian Institution, Washington, DC. These apes had been free shot, with sex determination readily available from the soft tissues. The ape species include: the orangutan, *Pongo pygmaeus*, the common West African chimpanzee, *Pan troglodytes*, and the Western lowland gorilla, *Gorilla gorilla gorilla*. Four specimens (two males, two females) of the mountain gorilla, *Gorilla gorilla beringei*, were also included in the gorilla sample. Since the focus of the research was on species-level dimorphisms, it is not expected that the inclusion of these few specimens of the mountain gorilla subspecies will significantly impact the results.

Measurements

The sciatic notch was measured with coordinate calipers (Fig. 1) to determine the relative proportions of the posterior (A-P) and anterior chords (B-P) where "P" is the intersection of the maximum breadth and maximum depth. The measurements were taken

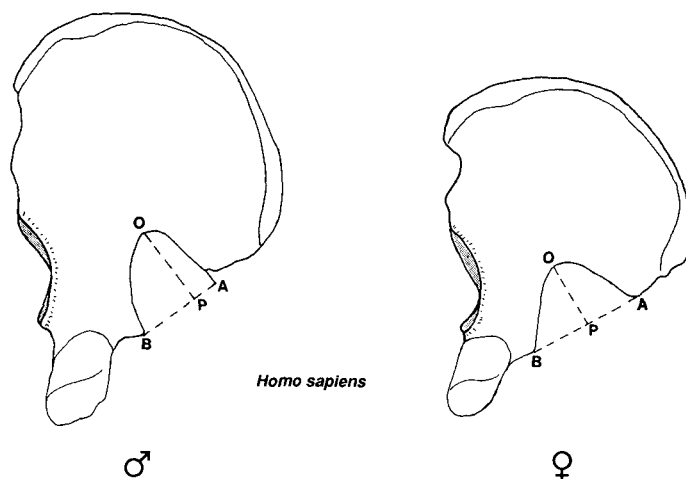


Fig. 1. Measurements of the sciatic notch of male and female left hipbones of *Homo sapiens*. Maximum breadth (AB); anterior chord (BP); posterior chord (AP); and maximum depth (OP).

on the left hipbone of all modern taxa; each specimen was measured twice. A test series of 25 individuals (human and non-human) was measured prior to the study to ensure consistency in the location of the morphological landmarks. Four measurements were taken on the sciatic notch using this technique:

1. Maximum breadth (AB): measured from the posterior inferior iliac spine at the posterior border of the greater sciatic notch to the ischial spine.
2. Maximum depth (OP): the greatest depth of the notch perpendicular to the line formed by the maximum breadth.
3. Anterior sciatic (BP): the anterior chord of the sciatic notch measured from the ischial spine to the point of intersection of the greatest depth and the greatest breadth.
4. Posterior sciatic (AP): the posterior chord of the sciatic notch measured from the posterior border of the sciatic notch (at the point of contraflexion) to the point of intersection of the greatest depth and greatest breadth.

Data analysis

Each taxon was analyzed separately by univariate and multivariate statistical methods. Males and females were separated during all aspects of the analysis. The data were

analyzed using SYSTAT and STATGRAPHICS statistical software packages.

A one-way analysis of variance (ANOVA) was performed on each of the four dependent variables for each taxon. Summary statistics and F-ratios were calculated to test the null hypothesis that for each dependent variable each group (sex) has the same mean.

Discriminant function analysis was used to achieve maximum separation between the sexes for each taxon using the sciatic notch variables (Klecka, 1980; Giles, 1970; Giles and Elliot, 1963). Since there is a linear relationship between the maximum breadth and the anterior and posterior chords, maximum breadth was omitted from the multivariate analysis. The three remaining variables (anterior chord, posterior chord, and maximum depth) were subjected to discriminant function analysis in order to determine: (1) how sexually dimorphic each taxon was for these dimensions of the sciatic notch; and (2) the relative contribution of each variable to the discriminant function.

RESULTS

Univariate analysis

Descriptive statistics and the univariate F-ratios appear for the four extant taxa in Tables 2–5.

In modern humans (Table 2), the male exceeds the female in absolute dimensions of

TABLE 2. *Sciatic notch: Means, standard deviations, standard errors, and univariate F-ratios^a for Homo sapiens*

Variables	Females			Males			F-ratio ^b
	Mean	SD	SE	Mean	SD	SE	
Maximum breadth	46.5	8.47	1.19	40.3	7.50	1.07	14.747***
Anterior chord	22.1	4.26	0.60	24.6	5.07	0.72	6.735*
Posterior chord	24.3	4.66	0.65	15.9	3.69	0.53	98.996***
Maximum depth	29.1	5.63	0.79	34.1	6.00	0.861	3.045***

^a All measurements in millimeters.^b df 1,98.* $P < 0.05$, *** $P < 0.001$.TABLE 3. *Sciatic notch: Means, standard deviations, standard errors, and univariate F-ratios^a for Gorilla gorilla*

Variables	Females			Males			F-ratio ^b
	Mean	SD	SE	Mean	SD	SE	
Maximum breadth	82.3	6.95	1.45	88.9	12.47	2.60	4.895*
Anterior chord	52.7	6.45	1.34	60.1	12.84	2.68	6.193*
Posterior chord	29.6	5.90	1.23	29.1	4.90	1.02	0.106 NS ^c
Maximum depth	20.0	3.66	0.76	23.1	2.84	0.59	10.350**

^a All measurements in millimeters.^b df 1,44.^c NS = not significant.* $P < 0.05$, ** $P < 0.001$.TABLE 4. *Sciatic notch: Means, standard deviations, standard errors, and univariate F-ratios^a for Pongo pygmaeus*

Variables	Females			Males			F-ratio ^b
	Mean	SD	SE	Mean	SD	SE	
Maximum breadth	71.6	10.37	2.77	77.1	8.76	9.92	1.710 NS ^c
Anterior chord	38.4	7.12	1.90	43.1	6.39	2.13	2.557 NS
Posterior chord	32.9	6.64	1.77	34.0	4.30	1.43	0.183 NS
Maximum depth	17.2	2.89	0.77	20.3	3.35	1.12	5.373*

^a All measurements in millimeters.^b df 1,21.^c NS = not significant.* $P < 0.05$.

the anterior chord and maximum depth, whereas the female sciatic notch exceeds the male for the posterior chord and maximum breadth dimensions. The most statistically significant difference between the sexes in modern humans is the posterior chord ($P < 0.001$); the least significant is the anterior chord ($P < 0.05$). In terms of relative proportions, it is important to note that in females the anterior and posterior chords are of nearly equal proportions or the posterior chord exceeds the anterior one, but in modern human males the posterior chord is smaller than the anterior chord, confirming the earlier findings of Genovés (1954, 1959, 1963). Since the means of the anterior chord dimensions of the single-sex samples are more similar than those of the posterior chord, the differences in the maximum

breadth between human males and females appears to result mainly from differences in the posterior chord.

For gorillas (Table 3), the maximum depth of the notch ($P < 0.01$), maximum breadth ($P < 0.05$), and the anterior chord ($P < 0.05$) are statistically significant between the sexes. The posterior chord in gorillas does not statistically differentiate between males and females. In fact, the mean of the posterior chord for male and female gorillas differs only slightly, suggesting that the differences in the maximum breadth are primarily derived from differences in the anterior chord.

In orangutans (Table 4) there are statistically significant differences between the sexes only for the maximum depth ($P < 0.05$). In the other three measurements, the sciatic notch dimensions in male

TABLE 5. *Sciatic notch: Means, standard deviations, standard errors, and univariate F-ratios^a for Pan troglodytes*

Variables	Females			Males			F-ratio ^b
	Mean	SD	SE	Mean	SD	SE	
Maximum breadth	85.7	7.67	1.42	88.2	7.80	1.47	1.540 NS ^c
Anterior chord	49.9	5.43	1.01	53.6	6.29	1.19	5.652*
Posterior chord	36.0	6.15	1.14	34.6	4.65	0.88	0.972 NS
Maximum depth	18.4	3.03	0.56	19.5	2.64	0.50	1.913 NS

^a All measurements in millimeters.^b df 1,55.^c NS = not significant.* $P < 0.05$.TABLE 6. *Discriminant function analysis: Eigenvalues, canonical correlations, and Wilk's lambda*

	Eigenvalue	Canonical correlation	Wilk's lambda
<i>Homo sapiens</i>	3.023	0.867	0.249
<i>Gorilla gorilla</i>	0.511	0.582	0.662
<i>Pongo pygmaeus</i>	0.319	0.492	0.758
<i>Pan troglodytes</i>	0.139	0.350	0.878

orangutans are not significantly different than in orangutan females.

Likewise, for chimpanzees (Table 5) there is only one measurement significantly different between the sexes, the anterior chord ($P < 0.05$). For the other measurements, male and female chimpanzees are very similar.

Multivariate analysis

The results of the discriminant function analysis on the extant taxa appear in Tables 6–8.

The discriminant function derived for the *Homo sapiens* sample has the most significant discriminating power of the four extant taxa examined (Table 6). This is indicated by the high eigenvalue, high canonical correlation, and low Wilk's lambda. The discriminant function derived for the *Gorilla gorilla* sample has the second best capability to discriminate between the sexes, followed by *Pongo pygmaeus*. However, the discriminant functions for gorillas and orangutans are considerably weaker than for *Homo sapiens*. The discriminant function analysis for the *Pan troglodytes* sample produced low eigenvalues, a low canonical correlation, and a high Wilk's lambda, all of which indicate a weak ability to discriminate chimpanzee pelvises by the sciatic notch.

The standardized, unstandardized, and total structure coefficients are shown in Ta-

TABLE 7. *Discriminant function analysis: Standardized, unstandardized, and total structure coefficients*

	Standardized	Unstandardized	Total structure
<i>Homo sapiens</i>			
Ant. chord	-1.102	0.236	-0.293**
Post. chord	1.252	0.297	0.818**
Max. chord	0.526	-0.091	-0.395**
Constant		2.393	
<i>Gorilla gorilla</i>			
Ant. chord	0.777	0.077	0.320*
Post. chord	0.013	0.123	0.105
Max. chord	0.880	0.269	-0.145
Constant		10.487	
<i>Pongo pygmaeus</i>			
Ant. chord	0.363	0.053	0.299
Post. chord	0.211	0.036	-0.201
Max. chord	0.827	0.269	0.254
Constant		8.293	
<i>Pan troglodytes</i>			
Ant. chord	0.732	0.125	-0.038
Post. chord	-0.433	0.079	0.107
Max. chord	0.432	0.152	0.005
Constant		6.550	

* $P < 0.05$.** $P < 0.01$.TABLE 8. *Discriminant function analysis: Group centroids, classification results*

	Group centroid	Classified correctly
<i>Homo sapiens</i>		
Males	1.756	94%
Females	1.687	98%
<i>Gorilla gorilla</i>		
Males	0.699	70%
Females	-0.699	83%
<i>Pongo pygmaeus</i>		
Males	0.763	56%
Females	-0.432	79%
<i>Pan troglodytes</i>		
Males	0.373	71%
Females	-0.360	66%

ble 7. The standardized and total structure coefficients indicate the relative contribution of the associated variable to the discriminant function. In general, the larger the

standardized coefficient, the more important the contribution to the discriminant score. However, because the standardized coefficients consider the simultaneous contributions of the variables, when two or more variables are correlated their joint contribution to the discriminant function scores may be important but their standardized coefficients might be small. The use of total structure coefficients is another way of determining each variable's contribution to the discriminant score. The total structure coefficients are particularly good measures of the correlation of the discriminant scores to a particular variable because they are bivariate measures (Pearson product-moment correlations) of the variable and the discriminant scores. The unstandardized coefficients are used to obtain the discriminant function scores.

In the *Homo sapiens* sample, the anterior and posterior chords make the most significant contributions to the function, one in a positive direction (posterior chord) and one in a negative direction (anterior chord), as determined by the standardized coefficients. In contrast, the maximum depth contributes very little to the discriminant function and can therefore be interpreted as relatively unimportant as a sex discriminator relative to the anterior and posterior chords. The posterior chord as measured by the total structure coefficient is more highly correlated to the function than the other sciatic notch variables.

In the *Gorilla gorilla* sample the standardized coefficients suggest the maximum depth contributes more to the function than the other variables, although the anterior chord is still relatively important. The posterior chord makes an insignificant contribution to the discriminant function in gorillas. The total structure coefficient indicates the anterior chord is more highly correlated to the function than the other variables ($P < 0.05$).

In the *Pongo pygmaeus* sample the standardized coefficients suggest the maximum depth is significant to the function, although the total structure coefficients indicate none of the variables contribute much to the discriminant function.

In the *Pan troglodytes* sample, relative to the other variables, the anterior chord

makes the greatest contribution, although the total structure coefficients suggest that, as in *Pongo*, none of the variables are strongly correlated to the discriminant function.

The group centroids and classification results are presented in Table 8. The group centroids are based on the discriminant function scores and summarize the group's location in multivariate space. The distribution of a two-function analysis (i.e., males and females) around the group centroid can be represented by frequency histograms as shown in Figure 2.

In the *Homo sapiens* sample the distribution of males and females around the group centroids reveals excellent separation between the sexes for the sciatic notch, as indicated by the minimal amount of overlap in the discriminant function scores for males and females.

In the *Gorilla gorilla* and *Pongo pygmaeus* samples the overlap is greater between the sexes than in *Homo sapiens*, indicating the limited discriminating power for the sciatic notch variables in these ape species. In addition, as indicated by the positive values of the discriminant scores, male gorillas and orangutans are larger than females for the sciatic notch, rather than females being larger than males as in *Homo sapiens*.

In *Pan troglodytes* the overlap between the sexes is substantial, suggesting that this part of the pelvis is of little value in separating male and female chimpanzees.

The discriminating power of the variables can also be determined by the classification percentages of actual and predicted group membership for the extant taxa (Table 8).

For modern humans 94% of males were classified correctly as males while 98% of females were correctly classified in the female group. In gorillas, 70% of the males were classified as males whereas 83% of the females were correctly placed into the female group. In the orangutan sample, 56% of the males were correctly classified as males while 79% of the females were placed in the female group. In the chimpanzees 71% of the males were classified as males but only 66% of the females were correctly classified as females based on the sciatic notch. Except for *Pan*, males were misclassified nearly

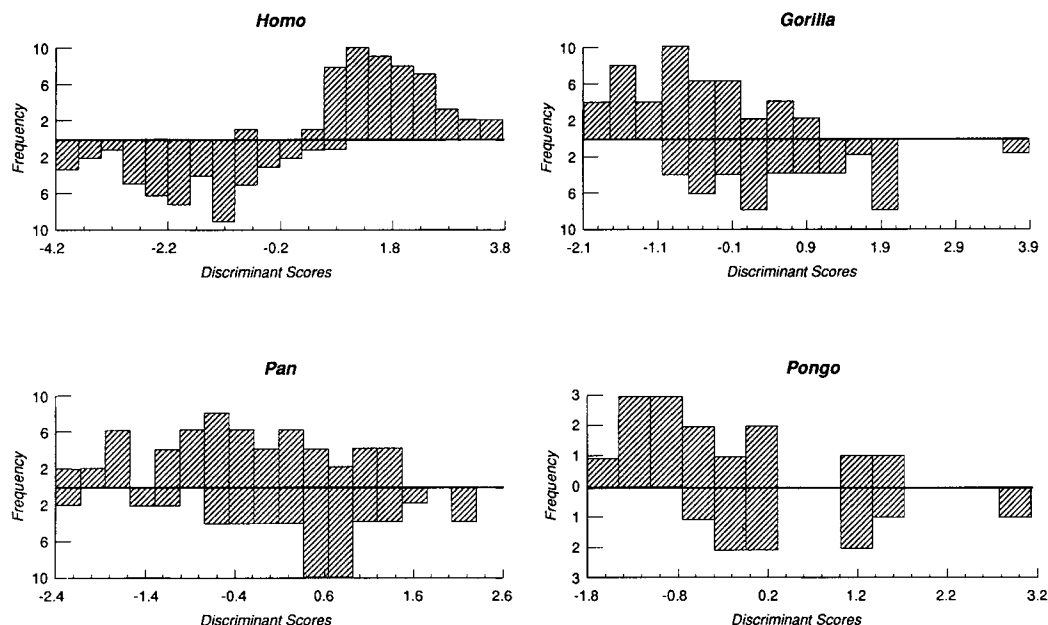


Fig. 2. Frequency histograms showing the distribution of males and females for the discriminant scores of the sciatic notch in *Homo*, *Gorilla*, *Pan*, and *Pongo* (females above, males below). Note that in *Homo* the amount of overlap is minimal due to the high discriminant value of the sciatic notch in modern humans.

twice as many times as females in the remaining three taxa. In other words, for the *Homo*, *Gorilla*, and *Pongo* samples, male pelvises appear female-like for the sciatic notch more often than females appear male-like.

DISCUSSION

Previous studies of the variation in pelvic dimorphisms among primates have focused on the relative importance of obstetrics and/or body size in determining the nature and extent of the dimorphism for any particular primate group (Leutenegger, 1974, 1982; Mobb and Wood, 1977; Rosenberg, 1992; Schultz, 1949; Steudel, 1981; Tague, 1991; Wood, 1976; Wood and Chamberlain, 1986). The sciatic notch, as only one variable, shows varying patterns of dimorphism among modern humans and the great apes.

The results of this study indicate that of the four extant taxa examined, modern humans have the most sexually dimorphic sciatic notch, followed by *Gorilla*, more weakly by *Pongo*, and with *Pan* having the least dimorphic sciatic notch of these taxa. The

sciatic notch of modern humans in fact shows a high predictive value for sex determination, with a particularly significant contribution coming from the differences in the posterior aspect of the notch. This is contrasted with the gorilla condition where differences in the maximum depth and anterior chord are responsible for discriminating between the sexes, albeit with a low predictive value. Even in orangutans, where the discrimination is slight to minimal, it is the maximum depth which is the most discriminating variable. Why is the length of the posterior chord so important to the determination of sex in modern humans and not in great apes?

Reproductive functions

Parturition is dependent upon a maternal pelvis adequate in both size and shape dimensions for delivery of the neonate. Like many species of monkeys (Schultz, 1949; Gingerich, 1972; Leutenegger, 1982), the upper limits of obstetrical constraints have been reached for modern human females

(Trevathan, 1987, 1988). Delivery of the human, macaque, and squirrel monkey newborn, for example, is often a difficult and lengthy affair due to the tight constraints placed on the female pelvis for the birth of a relatively large neonate (Schultz, 1949; Gingerich, 1972; Leutenegger, 1982). Human neonates are absolutely larger than those of any other primate (Napier and Naier, 1967), but as Rosenberg (1992) points out, human neonates are particularly unique in that the neonates are so large relative to the maternal body weight.

Sex differences in the modern human pelvis appear to derive principally from differential reproductive requirements in males and females (Gingerich, 1972; Hager, 1989; Leutenegger, 1974, 1982; Lovejoy et al., 1973; Schultz, 1949; Tague, 1989, 1991; Tague and Lovejoy, 1986; Wood and Chamberlain, 1986). However, Tague (1991) argues that some dimorphisms, such as biiliac diameter, sacral length, pelvic depth, and the anterior aspects of the inlet and midplane, may be related to the retention of ancestral hominoid traits. Frayer (1985) and Hager (1989) have suggested this may also be true of pubis length.

Dimorphism in the modern human sciatic notch has functional significance for success in parturition. The shape of the human female sciatic notch, with its large posterior component, ensures that the sacrum is positioned back and out of the birth canal, thereby increasing the anteroposterior dimensions of the midpelvis and pelvic outlet. The large posterior chord in human females to a great extent accounts for why the notch appears shallow and broad. On the other hand, in the typically narrow and deep notch of modern humans males, the short posterior aspect of the notch effectively brings the sacrum into the pelvic cavity, and thus reduces the overall dimensions of the midpelvis and pelvic outlet.

The upper posterior portion of the sciatic notch also contributes to the size and shape of the pelvic inlet. This was previously demonstrated by the chorematic index developed by Derry (1923) (Fig. 3). Noting differences in the length of the posterior segment of the iliopectineal line, Derry introduced the chilotic and chorematic indices as a means

of numerically differentiating this part of the human ilium by sex.

The chorematic index, which considers the posterior pelvic chilotic (BD) in relation to the anterior pelvic chilotic (AB) (Fig. 3), measures how close the greater sciatic notch is to the auricular point. In human females, the posterior pelvic segment is greater than the anterior one, suggesting that in females the auricular point is farther away from the apex of the sciatic notch than it is in males. The modern human results presented here confirm those of Derry's by indicating that the main differences in the upper portion of the sciatic notch of males and females are in the posterior aspect rather than in the anterior one. Thus, at least in part due to these differences in the superior aspect of the sciatic notch, the overall pelvic capacity at the pelvic inlet is larger in modern human females compared to modern human males.

In great apes, on the other hand, reproductive success is not dependent upon the female having a differentially large true pelvis than male great apes because great ape newborns are small relative to maternal pelvic size with correspondingly quick, easy deliveries (Galdikas, 1982; Leutenegger, 1973, 1974, 1982; Napier and Napier, 1967; Schultz, 1969; Stewart, 1977). In fact, unlike modern humans where in absolute and relative terms the true pelvis is larger in females than males, the male pelvis in orangutans and gorillas is larger than their female counterparts. Why then do gorillas and orangutans have any dimorphisms in their sciatic notch?

Gorillas and orangutans

Tague (1991) suggests that humans and great apes have similar levels of dimorphism for some pelvic variables due to our common hominoid heritage and/or to large body size rather than to obstetrics. Rosenberg (1992) however argues that while the *pattern* of dimorphism may be similar in closely related taxa for reasons other than obstetrics, the *degree* of dimorphism may be fundamentally different. The converse would also be true: more distantly related taxa may have similar degrees of dimorphism even while displaying different patterns of dimorphism.

In gorillas the maximum depth and ante-

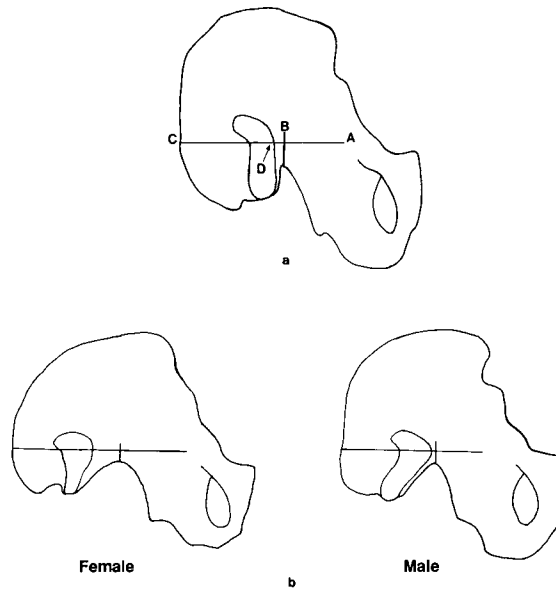


Fig. 3. Derry's (1923) chilotic line: **a**) anterior pelvic chilotic (AB); posterior chilotic (BD); and sacral chilotic (DC); **b**) female and male variations in the length of the posterior pelvic chilotic (BD); D = auricular point (letters the same as in a).

rior chord are the most dimorphic variables of the sciatic notch, whereas in orangutans it is the maximum depth only. However, these variables only minimally separate the sexes compared to modern humans. The large size of the male gorilla and orangutan may account for the presence of these low-level sex differences since both gorillas and orangutans are highly sexually dimorphic in their body size. The greater maximum depth in orangutan and gorilla males results from a slightly expanded posterior ilium and a large, rugose posterior ilium. The long anterior arm, which results in the anterior chord being larger in male gorillas than in females, results from a longer ischium in males than females. These differences can be attributed to the overall large body size of male orangutans and gorillas when compared to the females.

However, body size alone cannot explain why gorillas and orangutans might be sexually dimorphic in the sciatic notch region. One of the most surprising results of this study is that orangutans are not very sexually dimorphic in the sciatic notch region, especially when compared to how sexually

dimorphic they are in overall body size. Working under the premise that body size was the main determinant of sciatic notch sex differences in these highly dimorphic great apes, it was expected that orangutans would be just as sexually dimorphic as gorillas for this trait; but the orangutan was less dimorphic than the gorilla for the sciatic notch, and in fact orangutans closely approximated the low level of dimorphisms evidenced in chimpanzees. Why should orangutans and gorillas, where males are generally twice as large as females, show different levels of dimorphism in this part of the pelvis?

This discrepancy may be accounted for by differences in the locomotor patterns of gorillas and orangutans. Gorillas are primarily terrestrial, and are known to feed, nest, and travel on the ground. Females and young are more often found in the trees than males, although neither tends to engage in suspensory feeding postures (Fossey, 1983). The orangutan, on the other hand, is principally arboreal and engages in suspensory behaviors. The females and young are completely arboreal whereas male orangutans occasion-

ally travel between the trees on the ground (Galdikas, 1981; 1982).

It might be expected that orangutans would be more sexually dimorphic in their upper limbs than their lower ones because of the transmission of weight through the upper limbs in a suspensory pattern of locomotion. By contrast, in the terrestrial gorilla the large size of the male gorilla would require a hindlimb strong enough to support it; therefore gorillas would exhibit the effects of sexual dimorphism in their hindlimb areas more readily than do orangutans. These dimorphic features would not be related to obstetrics but rather to body size, posture, and locomotion.

Chimpanzees

The minimal level of dimorphism in the sciatic notch of chimpanzees is not surprising when considering the moderate levels of dimorphism seen in their body size. Moreover, chimpanzees have not demonstrated different locomotory patterns between the sexes as in orangutans, nor in reproductive requirements as in modern human females. The anterior chord was the only variable which weakly separated the sexes in chimpanzees. A moderately longer anterior arm in male chimpanzees probably corresponds to a longer ischium in male chimpanzees on par with differences in their body size.

Misclassification of males

The greater percentage of misclassification of male gorillas, orangutans, and humans in this study suggests that the male sciatic notch is more variable than the female one in these taxa.

In humans, misclassification was at a low level for both sexes, even though males were placed into the female group slightly more often than females (4% difference in male/female classification results). These data support Tague (1989), who failed to find a high level of pelvic variability among modern human females and males. A strong correlation between sciatic notch morphology and reproductive success in modern humans would predict that the male sciatic notch is more likely to vary without serious consequences to the reproductive fitness of the male, while in females any variation might

significantly reduce fitness. This probably explains why females were not misclassified as often as males, but nonetheless fails to completely answer the question why modern human males are not then misclassified more than they are. Perhaps the male pelvis, evolving solely under selection pressures for efficiency at bipedalism, has reduced the distance between the sacroiliac joint and the acetabulum to a minimum distance by having a short posterior sciatic notch chord. By contrast, the modern human female pelvis, with a large posterior sciatic notch chord, keeps that same distance at a maximum level whereby the female is still efficient at bipedalism but also insures the successful delivery of the large human neonate. Thus neither males nor females vary much in the sciatic notch in modern humans, males for reasons related to bipedalism, and females for reasons related to bipedalism and reproduction.

In gorillas and orangutans, the male sciatic notch looks like that of females almost twice as often as females resemble males. It is important to remember, however, that none of the great ape taxa are as sexually dimorphic as modern humans for the sciatic notch, and therefore, overall, these traits do not strongly separate between the sexes. Nonetheless, it is interesting to note the trend toward the misclassification of males rather than females in gorillas and orangutans (13% difference in male/female classification results for gorillas; 23% difference in orangutans). Do male gorillas and orangutans vary more in their sciatic notch morphology than females?

In gorillas, if differences in body size account for differences in sciatic notch morphology, these data would suggest that male gorillas show greater variability in the effect of body size on that morphology than females, or that male gorillas are more variable in their body size than are females. Additional research which incorporates the known body sizes of these gorillas will need to be done before this question can be adequately answered.

In orangutans, on the other hand, the percentage of misclassified males approaches 50%, which is the percentage expected to be misclassified if classification was due to random events. In other words, male orang-

utans in particular are quite variable for this trait.

Chimpanzees were also misclassified quite frequently, but in the opposite direction of the other taxa. Females were placed into the male group slightly more often than males (5% difference in male/female classification results). Given the fact that chimpanzees are not very dimorphic in their sciatic notch morphology and that the differences between males and females in classification were relatively low, these results do not appear to be indicative of a pattern of significantly greater variability in one sex over the other.

Bipedalism in hominids

In hominids, the morphology of the ilium and ischium is clearly divergent from the great ape condition, probably as a consequence of the bipedal adaptation (Fig. 4). In modern humans, the posterior ilium is extended and pulled downward. The ilium is reduced in its total height and broadened anteriorly as well as posteriorly. The sacral articulation is rotated and more closely approximates the acetabulum. The ischium is shortened, with the ischial tuberosity more closely aligned with the acetabulum. The ischial spine is more prominent in hominids than in great apes. This restructuring of the hominid ilium and ischium has been related to functional changes in the hominid pelvis for the bipedal gait (Straus, 1927, 1929; Mednick, 1955; Le Gros Clark, 1955; Chopra, 1962; Robinson, 1972; Lovejoy et al., 1973; Sigmon, 1986).

As a consequence of these changes in the posterior ilium and ischium in hominids, the sciatic notch became a well defined morphological feature. The anterior arm is shortened and the posterior ilium is brought downward to more or less "create" a notch due to selection pressures related to bipedalism, rather than selection pressures related to reproduction. Therefore, modern human males and females differ significantly in the overall configuration of the sciatic notch compared to great apes. While these changes appear to be directly related to selection pressures for the bipedalism, they may have subsequently impacted the repro-

ductive nature of the maternal pelvis (Tague and Lovejoy, 1986; Rosenberg, 1992).

SUMMARY AND CONCLUSIONS

Sex differences in the sciatic notch similar to those of modern humans, where dimorphism reaches significant levels, need not have occurred at the transition to bipedality, but could have developed subsequent to it (Hager, 1989; Tague, 1991). Our last common ancestor with the great apes probably had a sciatic notch no more well defined than that of modern great apes, including the same minimal level of sex differentiation. Such a sciatic notch would have had a long anterior arm and a posterior aspect that remained in the dorsal position, as we see in modern great apes. If sex differences in the modern human sciatic notches are functionally related to successful delivery of large neonates, there may not have been the same level of dimorphism in the notch of the earlier smaller-brained hominids whose infants may have been significantly smaller relative to the maternal pelvis. In other words, the early hominids may have more closely resembled the great ape condition of little or no sex differences in the sciatic notch.

To summarize:

1. In modern humans, the sciatic notch clearly discriminates between males and females when the relative proportions of the posterior and anterior chords are examined as previously demonstrated by Genovés (1953, 1959). Genovés' technique is an accurate, straightforward approach to sexing the modern human hipbone based on the sciatic notch.
2. The great apes are not as sexually dimorphic in the sciatic notch as modern humans. *Pan* is the least dimorphic for the sciatic notch of all the modern taxa examined. *Pongo* is only slightly more dimorphic than chimpanzees, and gorillas are the most dimorphic of the great ape taxa.
3. The posterior chord makes the greatest contribution to the presence of sex differences evident in the sciatic notch in modern humans. In gorillas, the maximum depth and anterior chord sepa-

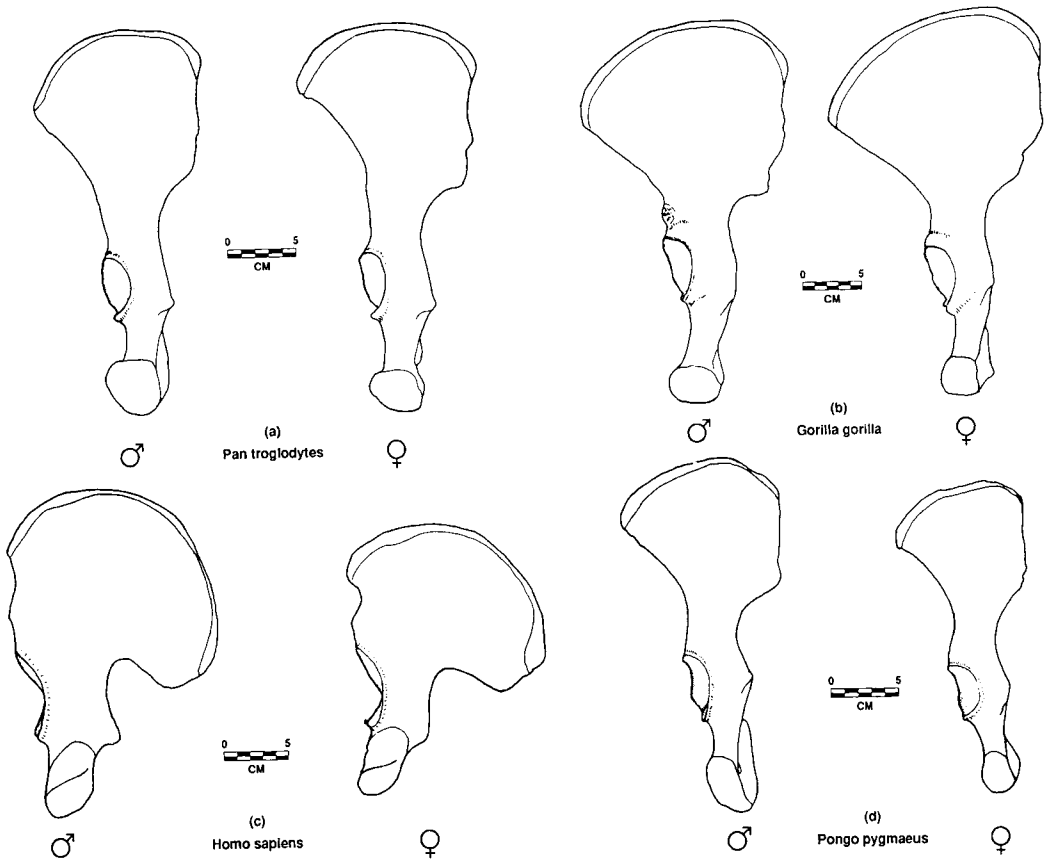


Fig. 4. Gluteal views of male and female left hipbones from (a) *Pan troglodytes*, (b) *Gorilla gorilla*, (c) *Homo sapiens*, and (d) *Pongo pygmaeus*. For *Homo sapiens* in particular, note the contribution of the posterior portion of the ilium in the accentuation of the greater sciatic notch. In addition, the anterior arm of the sciatic notch is shortened in *Homo sapiens*.

rate the sexes, in orangutans it is the maximum depth, and in chimpanzees none of the sciatic notch variables are able to significantly distinguish between the sexes.

4. Differences in the degree of sciatic notch dimorphism within the three great ape species might be accounted for by: (1) differences in body size dimorphisms; and (2) differences in locomotor patterns. Reproductive functions do not appear to affect the size and shape of the sciatic notch in great apes.
5. Males were misclassified more than females for all modern taxa, except chimpanzees where the reverse is true. This suggests that males are more variable

for this trait than are females for modern humans, gorillas, and orangutans. In chimpanzees, the percentage of correctly classified individuals is low for both males and females, suggesting that there is more variability within the sexes for this feature than between them.

6. The modern human sciatic notch is well defined when compared to the great apes due to the restructuring of the hominid ilium and ischium as part of the bipedal adaptation. In hominids, bipedalism accounts for the unique configuration of the sciatic notch.
7. Modern human-like sex differences in the sciatic notch of hominids are likely

to have occurred subsequent to the transition to bipedality, rather than coincident with it.

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